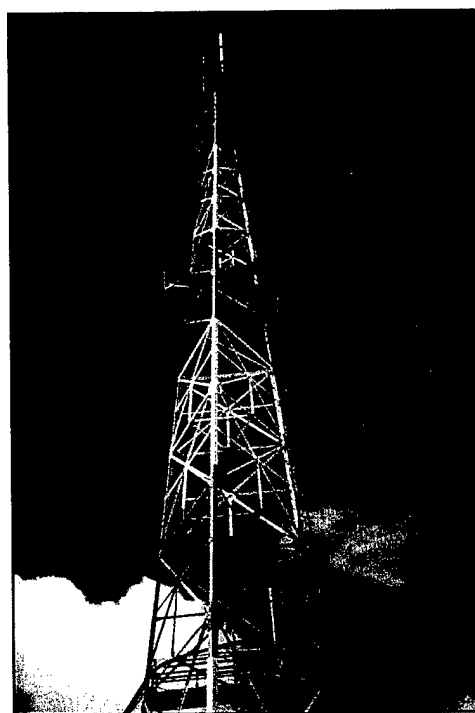




NAVAL FACILITIES ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

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MOISTURE CURED URETHANE (MCU) COATINGS FOR USE ON ANTENNA TOWERS: A FEASIBILITY STUDY



by
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July 1999

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13. ABSTRACT (Maximum 200 words) A feasibility study on the use of Moisture Cured Urethane (MCU) coatings for large antenna towers was conducted. Results are as follows: 1) MCU coating systems are performing well on Oregon's coastal bridges, 2) MCU coatings will produce a somewhat acceptable bond to either a damp or wet substrate, 3) MCU coatings form excellent bonds to both blasted steel and to MCU intercoats, 4) Aliphatic MCU topcoats exhibit a decrease in color retention and gloss when subjected to QUV Accelerated Weathering, 5) MCU application by either mitt or brush may producing unacceptable bubbling (pinholes), 6) Federal Highway Administration (FHA) research concludes that MCU coatings provide excellent barrier protection, however, all MCU coatings are not equivalent and require testing prior to use, 7) A Relative Humidity (RH) below 30 % may produce unacceptable slow curing, whereas, a RH above 83 % may produce too fast of a cure with unacceptable bubbling, 8) MCU coatings with xylene may cause film bubbling when DFTs exceed 3.0 mils, 9) MCU topcoats employing 100% aliphatic resins, when compared to two-component aliphatic urethanes, give rise to lower UV resistance. NFESC does not recommend MCU coating systems for use in painting erected antenna towers.				
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EXECUTIVE SUMMARY

This effort is in response to a request by the Naval Facilities Engineering Command (Atlantic Division) on behalf of the Naval Computer and Telecommunications Command to perform a feasibility study on the use of Moisture Cured Urethane (MCU) coating systems for large antenna towers. The feasibility study consisted of the following: A) Site visit to Oregon's Coastal Bridges, B) Identification and procurement of MCU coating systems with topcoats in two Federal Aviation Administration (FAA) colors (white, red-orange), C) Laboratory testing (application to wet substrate, FTIR analysis, adhesion testing, QUV accelerated weathering, UV/VIS spectral analysis, specular gloss, application by mitt and brush), D) Conversations with industry experts, and E) Literature survey.

Results from the feasibility study are as follows: 1) MCU coating systems are performing extremely well on coastal bridges located in Oregon, 2) Once the moisture is displaced, MCU coatings will produce a somewhat acceptable bond to either a damp or wet substrate, 3) MCU coatings form excellent bonds to both abrasively blasted steel and to MCU intercoats, 4) Aliphatic MCU topcoats, in general, exhibit a decrease in color retention and gloss when subjected to QUV Accelerated Weathering, 5) MCU application by either mitt or brush, even under controlled conditions, may produce unacceptable pinholes due to Dry Film Thickness (DFT) greater than 3.5 mils, 6) Research from the Federal Highway Administration (FHA) concludes that MCU coatings should provide excellent barrier protection in corrosive environments, however, all MCU coatings do not perform equivalently and should be tested prior to field use, 7) A Relative Humidity (RH) below 30 % may cause unacceptable slow curing, whereas a RH above 83 % may cause too fast of a cure with unacceptable carbon dioxide bubbling, 8) MCU coatings which contain the solvent xylene as either the principle or one of the solvent components may cause film bubbling when DFTs exceed 3.0 mils, 9) The use of MCU topcoats employing 100% aliphatic resins will contain large numbers of urea links which, when compared to two-component aliphatic urethanes, give rise to lower UV resistance.

At present, the Naval Facilities Engineering Service Center (NFESC) does not recommend MCU coating systems for use in the painting of erected antenna towers. If the antenna tower is in a disassembled state and transported to a painting shop where both application and environmental conditions are controlled, then MCU coating systems are acceptable for use on either new or existing antenna towers. NFESC recommends additional performance testing on coating systems, including MCU's, applied under the same extreme environmental conditions encountered in the field, using field application procedures. Up to fifteen high-performance coating systems should be selected and subsequently evaluated under the above conditions.

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INTRODUCTION

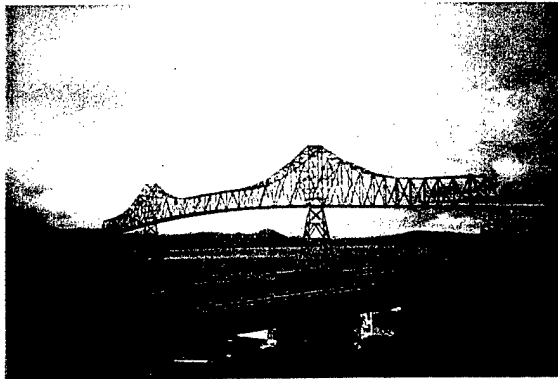
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BACKGROUND

In the field, Naval antenna towers have primarily been recoated, through application by mitt, using either one to two coats of epoxy polyamide followed by a topcoat of aliphatic urethane or, if galvanized, two coats of acrylic latex^{2, 3}. Epoxy polyamides and aliphatic urethanes used by the Navy are formulated in two components and, during both application and curing, require strict attention to relative humidity and temperature. The acrylic latex system is also bound by temperature requirements and, in addition, typically does not provide sufficient barrier protection to prevent corroded steel from further corrosion. MCU coatings, when compared to standard epoxies and urethanes, may offer the following field benefits: 1) Ease of use (single component), 2) Lower temperature and higher humidity ranges during application/curing, and 3) Equivalent performance.

SITE VISIT

Oregon's Department of Transportation (DOT) designated a section on the underside of the Astoria Bridge, located over the Columbia River on Oregon's Northwest coast, for testing potential bridge coating candidates. One study, which rated the performance of ten industrial coating systems over the course of six years, resulted in a MCU coating system (zinc rich primer, micaceous iron oxide intermediate, and an aliphatic topcoat) outperforming each of the nine tested coating systems. This study convinced Oregon's DOT to switch from their workhorse, two coats of either epoxy polyamide or epoxy polyamine followed by a topcoat of two-component aliphatic urethane, to coating systems consisting of MCU. At present, the Astoria Bridge contains MCU coating systems that have been in service for up to six years with, in general, high levels of performance (less than 0.5% coating failures). However, Oregon's DOT is experiencing some mild coating problems, on Astoria's Washington side, that are believed to be a result of improper application. Oregon's DOT feels that this is an isolated situation and anticipates a minimum of fifteen years maintenance-free service for MCU coating systems applied to coastal bridges. When comparing Oregon's past experiences with coating systems on coastal bridges, fifteen years of service, without overcoating, equates to a three-fold service life increase⁴.



1. Astoria Bridge, Oregon Side.



2. Astoria Bridge, Washington Side.

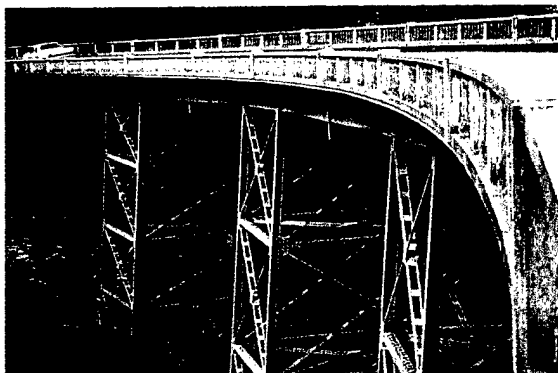


3. Close-up of Oregon Side.

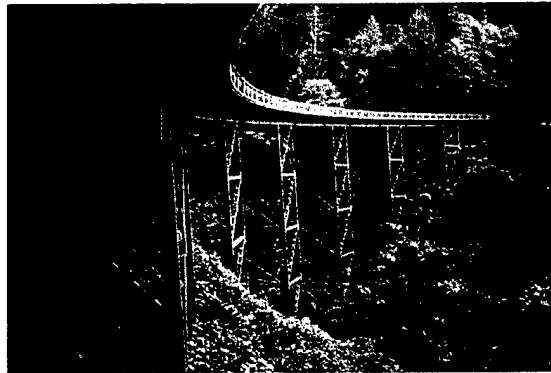


4. Close-up of Washington Side: Mild Rusting.

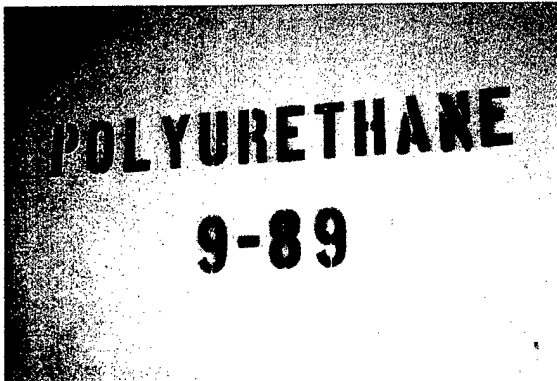
Oregon's Manzanita Bridge, located approximately one mile from the coast, was coated using an MCU coating system in 1989. At present, the coating system is performing quite well with less than 2.0 % visible rust, primarily located on edges. Oregon's St. John's Bridge, located a few miles west of Portland, is coated on the south side with a MCU coating system applied approximately five years ago. The coating system is in excellent condition with only negligible quantities of visible rust. However, the color of the guard railing, when compared to the bridge's underside, has faded several shades from its' original vibrant green to a light green pastel color. This observation implies that either the coating's green pigment or the MCU resin matrix is effected by sunlight and is degrading.



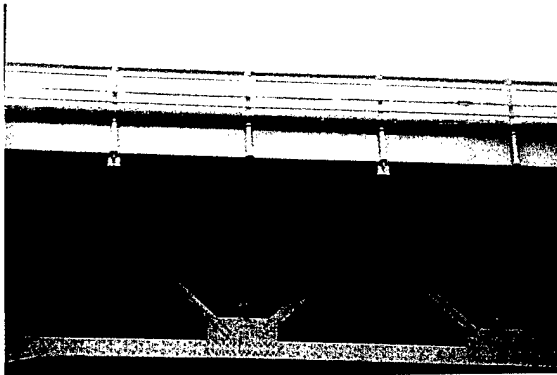
5. Manzanita Bridge, Oregon.



6. Manzanita Bridge, Oregon.



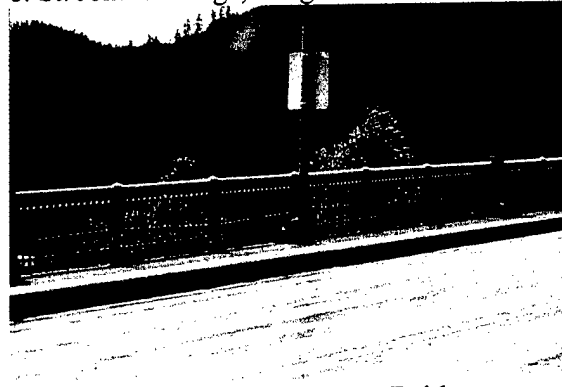
7. MCU on Manzanita Bridge since 1989.



9. Underside, St. John's Bridge.



8. St. John's Bridge, Oregon.



10. Guard Railing, St. John's Bridge.

EXPERIMENTAL

Eight coating manufacturers supplied MCU coating systems with topcoats in the two designated FAA Obstruction Marking Colors (white, red-orange) for testing. MCU primers and intermediate coats represent established commercial formulations, whereas the white and red-orange topcoats represent experimental laboratory formulations that are currently in the process of being tested and approved for field use. Laboratory testing consisted of the following: 1) Application to Wet Substrate, 2) FTIR Analysis, 3) Adhesion Testing, 4) QUV Accelerated Weathering, 5) UV/VIS Spectral Analysis, 6) Specular Gloss, and 7) Application by Mitt and Brush.

COATING SYSTEMS

The letters A through H were assigned to each coating system tested. Listings of coating systems and vendors, corresponding to assigned letter, are presented in Appendix A. The below is a list, by combined pigment and resin type, of the coating systems tested.

Coating System A

Primer: Aluminum Rich, Aromatic Urethane
Topcoat: Aliphatic Urethane

Coating System B

Primer: Red-oxide Rich, Aromatic Urethane
Intermediate: Aliphatic Urethane
Topcoat: Aliphatic Urethane

Coating System C

Primer: Zinc Rich, Aromatic Urethane
Topcoat: Aliphatic Urethane

Coating System D

Primer: Two-Component, Epoxy-Acrylic (Waterborne)
Topcoat: Acrylic-Aliphatic Urethane (Waterborne)

Coating System E

Primer: Zinc Rich, Aromatic Urethane
Intermediate: Micaceous Iron Oxide, Aromatic Urethane
Topcoat: Aliphatic Urethane

Coating System F

Primer: Zinc Rich, Aromatic Urethane
Topcoat: Aliphatic Urethane

Coating System G

Primer: Aliphatic Urethane
Intermediate: Aliphatic Urethane
Topcoat: Aliphatic Urethane

Coating System H

Primer: Zinc Rich, Aromatic Urethane
Topcoat: Aliphatic Urethane

Table 1 contains properties from manufacturers' literature representing several of the zinc rich primers evaluated.

Table 1: Standard Properties of Zinc-Rich Primer

Volatile Organic Compounds (VOC)	≤340 g/l
Volume Solids	62.0 ± 2.0 %
Percent Aromatic Urethane Resin	100%
Percent Zinc in Dry Film by weight	80.0 ± 2.0 %
Elcometer™ Adhesion (ASTM D 4541)	≥500 psi
Maximum Dry Film Thickness	3.0 mils
Flexibility (ASTM D 522) 180° bend ¼" mandrel	Pass
Pot Life at 50% R/H and 75°F	4 – 6 hours minimum
Recoat Time at 50% R/H, 75°F, and 3 mils DFT	4 – 6 hours minimum
Substrate Application Temperature Range	40°F - 100°F
Relative Humidity during Application	30% - 95 %

Table 2 contains properties from manufacturers' literature representing several of the topcoats evaluated.

Table 2: Standard Properties of Topcoat

Volatile Organic Compounds (VOC)	≤340 g/l
Volume Solids	62.0 ± 2.0 %
Pigments (ASTM D 4834)	Lead and Chromate Free
Percent Aliphatic Urethane Resin	100 %
White Color (Fed. Std. 595B)	#17875
Red/Orange Color (Fed. Std. 595B)	#12197
Specular Gloss 60° White (ASTM D 523)	≥70
Specular Gloss 60° Red/Orange (ASTM D 523)	≥70
Elcometer™ Adhesion (ASTM D 4541)	≥500 psi
Maximum Dry Film Thickness	3.0 mils
Flexibility (ASTM D 522) 180° bend 1/8" mandrel	Pass
Pot Life at 50% R/H and 75°F	4 – 6 hours minimum
Recoat Time at 50% R/H, 75°F, and 3 mils DFT	4 – 6 hours minimum
Substrate Application Temperature Range	40°F - 100°F
Relative Humidity during Application	30% - 95 %

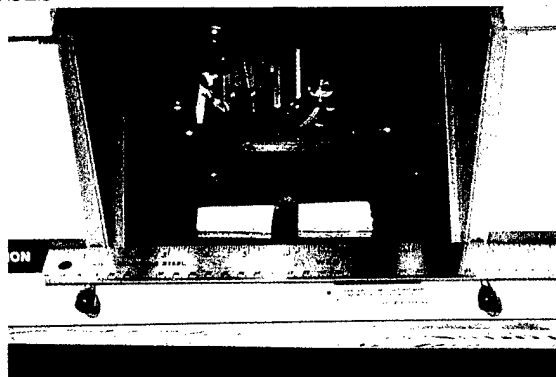
PREPARATION OF TEST PANELS

Prior to coating, each 6" x 12" (11 gauge sheet metal) test panel was solvent washed and abrasively blasted to a white metal finish. Six test panels were coated per coating system with the following topcoats: two white, two red-orange, one white (wet between coats), one red-orange (wet between coats). All coatings were applied by brush and in accordance with manufacturer's recommendations except for the coatings applied to wet surfaces (see below).

APPLICATION TO WET SURFACES

The following procedure was performed on two test panels per coating system to determine the performance of MCU coatings applied to damp surfaces: A fine mist of de-ionized water was sprayed onto the blasted steel substrate immediately before priming and, in addition, prior to all subsequent coats. Based on visual observations during the application of coatings, none of the coating systems appeared to tolerate a damp surface. At best, the water became displaced by forcefully brushing the paint onto the panel. Once the water was displaced, the coatings formed somewhat satisfactory bonds to both the substrate and to previously applied coatings (see adhesion results below). Following adhesion testing, several sections of the cured coating systems were removed to bare steel to visually reveal significant levels of rust in lieu of the former white metal surface. Results suggest that the application of MCU coatings to damp surfaces will decrease the coating system's performance and should be avoided.

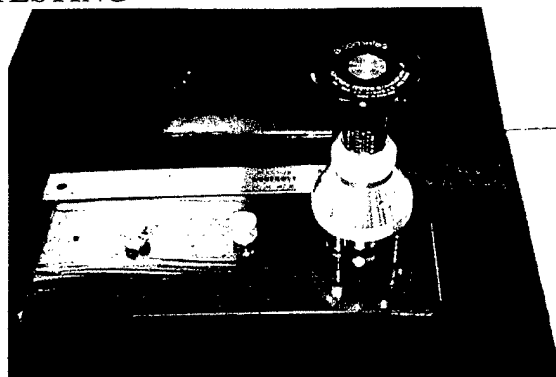
FTIR ANALYSIS



11. Bio Rad™ Fourier Transform Infrared Spectrometer (FTIR).

A Bio Rad™ Fourier Transform Infrared Spectrometer (FTIR) was used to chemically fingerprint each of the white and red-orange topcoats evaluated. Appendix B contains spectral printouts and a written summary detailing significant absorption peaks, functional groups identified, and a brief description of the results. FTIR results provided insight into the chemical formulation of the topcoats and, in addition, will be useful in establishing baseline quality control parameters if future coating specifications are to be designed.

ADHESION TESTING



12. Elcometer™ Portable Adhesion Tester with 3/4" Aluminum Pull-Off Coupons.

Adhesion testing in accordance to ASTM D 4541 (Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers⁵) was performed on coating systems applied under both standard (dry) and wet surface conditions. Three 3/4" aluminum pull-off coupons were glued, using a two-component five minute epoxy, to four test panels per coating system: white topcoat (dry), white topcoat (wet), red-orange topcoat (dry), red-orange topcoat (wet). It became apparent, when pulling-off the aluminum coupons, that the selected adhesive was significantly weaker than the coatings tested. Numerous glue failures occurred well before maximum coating adhesive strengths could be quantified. Nevertheless, all coating systems applied under the standard dry conditions developed sound coating bond strengths, to both the substrate and to intercoats, at or above 400 psi. All coating systems applied to wet surfaces experienced bond strengths at or above 280 psi with disbonding primarily resulting from intercoat and substrate adhesion loss. Results from wet surface adhesion testing indicate

that applying MCU systems onto wet surfaces will reduce coating bond strengths which, in effect, will reduce the coating's service life.

QUV ACCELERATED WEATHERING

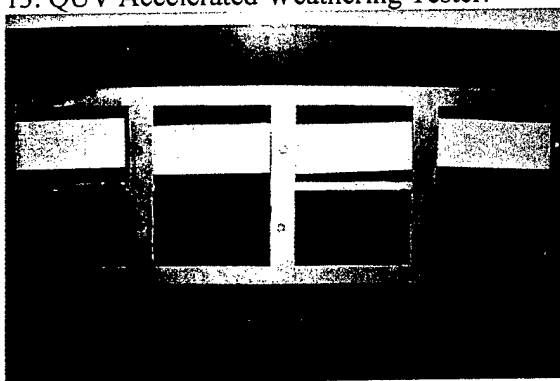
Four coated test panels (two white topcoat, two red-orange topcoat) per coating system were placed into two QUV Accelerated Weathering Test Units. Each QUV unit ran for a total of 3,000 hours and was programmed to run on one of the following two Schedules: 1) Alternating cycling between 4 hours water spray without UV (70°F) and 4 hours heating with UV (140°F), and 2) Continuous heating with UV (140°F). QUV testing was performed to determine color and gloss retention per topcoat and, in addition, overall degradation due to accelerated weathering. Both prior to and after QUV testing, topcoats were evaluated for Specular Gloss and UV/VIS Spectral Absorbance (see results below). In order to perform the UV/VIS spectral analysis, two additional samples (sample size: 2 in²) per coating system were placed into the QUV unit programmed with Schedule #2. After 3,000 hours exposure from either Schedule 1 or Schedule 2, test panels, in general, exhibited visually observed decreases in color and gloss retention as the primary signs of coating degradation except Coating System D (water-based Coating System D, subjected to Schedule 1, developed a bond, in the area of test panel/test rack overlap, which required significant force to remove: bond suggests that Coating System D may not be highly resistant to water). A decrease in both color and gloss retention was clearly observed when comparing exposed test panel surfaces to those covered by the test rack. Coated test panel areas covered by the test rack appeared several shades brighter with higher gloss than the adjacent exposed panel surfaces. When compared to the white topcoats, the red-orange topcoats contained the greatest degree of color retention loss.



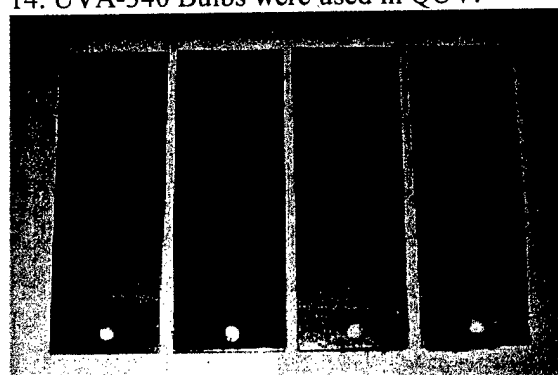
13. QUV Accelerated Weathering Tester.



14. UVA-340 Bulbs were used in QUV.



15. Sample Rack used for QUV.



16. Samples after 3,000 hrs. Schedule #2.

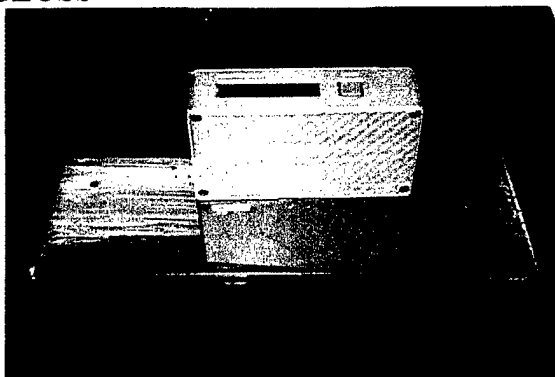
UV/VIS SPECTRAL ANALYSIS



17. Perkin Elmer™ UV-VIS Spectrophotometer with 2" Sample.

A Perkin Elmer™ UV/VIS Spectrophotometer was used to evaluate color changes in coating systems subjected to 3,000 hours of Schedule #2 QUV exposure. For each topcoat, three two-inch square samples, cut from the 6" x 12" test panels, were used for the UV/VIS evaluation. Two samples per topcoat color were used to establish baseline visible and UV spectral parameters whereas the third was placed in the QUV and evaluated after 3,000 hours of Schedule #2 exposure. Appendix C contains two spectral printouts per coating system (white topcoat, red-orange topcoat) and shows the two baseline standards superimposed upon the UV exposed sample (absorbance in the visible range (VIS) is at a wavelength from 400 – 700 nanometers (nm), whereas absorbance in the ultra-violet range (UV) is from 200 – 400 nm). The UV-VIS instrument measures the amount of ultraviolet and visible energy absorbed by a coating and, in addition, may be used to correlate chemical changes within the coating. Although several coatings exhibited decreases in both gloss and color retention after QUV exposure, the UV-VIS spectral printouts did not conclusively show either significant increases or decreases in absorbance whereby spectral trends could be identified. Either further UV-VIS spectral analysis or other color analysis is required to quantitatively determine the subtle trends within each spectral printout.

SPECULAR GLOSS



18. Gardco® micro-TRI-gloss: Specular Gloss Unit (20°, 60°, 85°).

A Gardco® micro-TRI-gloss was used at an angle of 60° to evaluate specular gloss on four test panels per coating system, both prior to and after QUV exposure (two panels per Schedule). Gloss values are presented in Appendix D and represent the average of ten readings per gloss value. The specular gloss scale ranges from 0 – 100 where high gloss

surfaces contain values greater than 85 at a 60° angle. The highest initial gloss value for white was 85.6 (Coating System H) and the highest initial gloss value for red-orange was 84.5 (Coating System E). A shift in specular gloss, such as a gloss decrease, represents a surface that has begun to degrade. However, twelve out of the thirty-two panels evaluated actually exhibited a gain in specular gloss following QUV exposure. One potential explanation is that several of the coated panels retained the high and low ridges resulting from application by brush. These ridges may have affected the accuracy of the gloss meter's readings. Overall, the red-orange topcoats subjected to Schedule #2, except Coating System F, exhibited slightly higher decreases in gloss when compared to their white counterparts (Coating System F's initial gloss value prior to Schedule #2 exposure was 25.1 which shifted to the lowest recorded value of 11.8). However, differences in the gloss values between red-orange and white topcoats do not appear to be significant and, as such, these topcoats should lose their gloss at a rate approximately equivalent.

APPLICATION BY MITT AND BRUSH

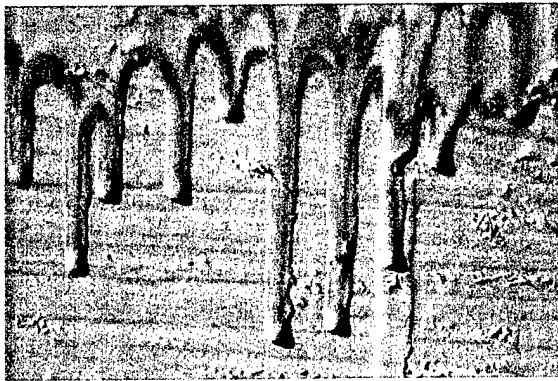
To simulate application procedures employed on Naval antenna towers, the following demonstration was performed. One 2' x 2' x 1/8" sheet metal panel (horizontal application) and one vertical surface of a steel wall were coated with one coat of a zinc rich primer (properties identical to those listed in Table 1) using a synthetic mitt with a 3/8" nap. One additional sheet metal panel was coated with one coat of the above zinc rich primer by brush (horizontal application). The Dry Film Thickness (DFT) of the primer applied to each panel was measured 30 hours following paint application using an Elcometer™ Model 345 Magnetic Gauge. Application by mitt produced DFTs ranging from 1.5 – 5.4 mils (1 mil = 1/1000 inch), whereas, application by brush produced DFTs ranging from 2.5 – 6.0 mils. MCU coating manufacturers recommend that DFTs remain below 3.0 mils per coat. Where DFTs were greater than 3.5 mils, bubbles (pinholes) were clearly visible. Pinholes allow water and salts direct access to the substrate whereby the coating, in the area of the pinhole, cannot protect the substrate against corrosion. Application by mitt produced runs and sagging on the vertical surface and, in addition, released synthetic fibers into the coating which may create a wicking effect. Wicking occurs when fibers become exposed and create a path of direct access for water and salts into the coating which, over time, may lead to a coating failure at the fiber's site. This demonstration identifies what may happen when a MCU is applied above 3.5 mils DFT and, in addition, the ease in exceeding 3.5 mils DFT when applying a MCU by either mitt or brush.



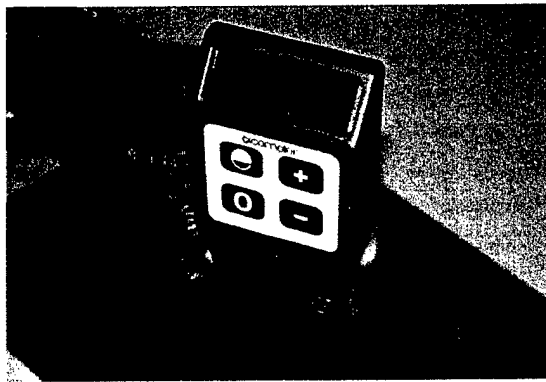
19. Application of Zinc Rich MCU by Mitt.



20. Application of Zinc Rich MCU by Brush.



21. Fast application by mitt on a vertical surface using a Zinc Rich MCU produced unacceptable runs and sagging. One day following photograph, runs contained pinholes.



22. Elcometer™ Model 345 Magnetic Dry Film Thickness (DFT) Gauge.

LITERATURE SURVEY

Four published articles and two reference books were identified which discuss the performance properties of MCU coating systems under either laboratory testing or field use. However, four out the six are based solely on qualitative performance results and were not included in this section. It appears that field performance results are known and expressed by both manufacturers and applicators, however, this information has not been documented through published literature. Results from one published article and one reference text are summarized below.

The Federal Highway Administration (FHA) conducted a recent investigation into the laboratory performance of MCU coatings⁶. The FHA tested three MCU coating systems: A) Zinc-rich primer, micaceous iron oxide intermediate, topcoat, B) Zinc-rich primer, micaceous iron oxide intermediate, micaceous iron oxide topcoat, C) Zinc-rich primer, micaceous iron oxide and aluminum filled intermediate, micaceous iron oxide topcoat. The primer and intermediate coats of each coating system contained mixtures of aromatic and aliphatic urethane resins, whereas, topcoats contained primarily aliphatic urethane resin. Three sets of five test panels per coating system were applied to abrasively blasted steel test panels and prepared under the following conditions: 1) Application of straight systems (control), 2) Application of straight systems with 2" diagonal scribe, 3) Coating systems applied over chloride doped substrate ($20 \mu\text{g}/\text{cm}^2$) with 2" diagonal scribe. Testing consisted of 4,000 hours of cyclical accelerated weathering (freeze/UV/Condensation/Cyclical Salt-fog) and adhesion testing. After 4,000 hours of accelerated weathering, results are as follows: A) All panels applied under Condition 1 contained no surface failures (gloss was not tested), B) Panels applied under Condition 2 showed blistering and undercutting up to 3.3 mm at scribe (failures appeared at 1500 hours), C) Panels applied under Condition 3 showed blistering and undercutting up to 5.1 mm at scribe. Adhesion test results ranged from 1550 psi to 1750 psi both prior to and after accelerated weathering (extremely high adhesion values). Conclusions from this study are that the tested MCU coatings should provide excellent barrier protection to steel in corrosive environments. However, and although the zinc-rich primers contained between 78 – 86% zinc in the dry film (by wt.), they did not provide sufficient cathodic protection to prevent undercutting at the scribe. Results suggest that spot rusting and

corrosive undercutting may occur in areas where the coating has been damaged. Furthermore, the authors firmly believe that all MCU coatings do not perform equivalently and, as such, should be tested for both formulation and performance properties prior to field use.

Within Clive H. Hare's book "Protective Coatings: Fundamentals of Chemistry and Composition", Chapter 16 details, along with several other topics, both the merits and shortcomings of polyurethane coatings⁷. Presented as follows is a summary, extracted from Chapter 16, which identifies three MCU coating limitations: 1) A Relative Humidity below 30% may produce unacceptable slow curing, whereas, a Relative Humidity above 83% may produce too fast of a cure with unacceptable bubbling due to the release of carbon dioxide, 2) MCU coatings which contain the solvent xylene as either the principle or one of the solvent components may cause film bubbling when DFTs exceed 3.0 mils, 3) The use of MCU topcoats employing 100% aliphatic resins will contain large numbers of urea links which, when compared to two-component aliphatic urethanes, give rise to lower UV resistance.

DISCUSSION

Optimum field application parameters for MCU coatings are almost identical to that of two-component epoxies and urethanes. MCU coatings perform best when applied under the following conditions: 1) Relative Humidity between 35 – 82 %, 2) Substrate and ambient air temperatures 5°F (3°C) above the dew point temperature, 3) Air and substrate temperatures between 40 – 100 °F (during both application and curing), 4) DFTs at or below 3.0 mils. Although applicators may be restricted from painting during low temperatures using two-component coatings (unmodified two component systems typically require minimum application temperatures of 50°F, 10°F higher than a MCU), this temperature limitation is offset by being able to apply the two-component systems at DFTs greater than 3.0 mils without producing pinholes from carbon dioxide bubbles (epoxies at 6+ mils DFT, two-component urethanes up to 4 mils DFT). Furthermore, aliphatic MCU topcoats, when compared to two-component aliphatic urethane topcoats, exhibit decreased gloss and color retention when exposed to sunlight. As such, antenna towers coated with two component urethane topcoats will retain the vibrant colors of their FAA stripes longer than if coated using a MCU topcoat.

When humidity and temperature requirements are met and coating applications are at or below 3.0 mils per coat, MCU coatings appear to be protecting structures against corrosion at a level approximately equivalent to two-component formulations. However, MCU coating systems, in general, are unable to form pinhole free films when applied at DFTs greater than 3.5 mils.

CONCLUSIONS

1. MCU coating systems are performing extremely well on coastal bridges located in Oregon.
2. Once the moisture is displaced, MCU coatings will produce a somewhat acceptable bond to either a damp or wet substrate.

3. MCU coatings form excellent bonds to both abrasively blasted steel and to MCU intercoats.
4. Aliphatic MCU topcoats, in general, exhibit a decrease in color retention and gloss when subjected to QUV Accelerated Weathering.
5. MCU application by either mitt or brush, even under controlled conditions, may produce unacceptable pinholes due to Dry Film Thickness (DFT) greater than 3.5 mils.
6. Research from the Federal Highway Administration (FHA) concludes that MCU coatings should provide excellent barrier protection in corrosive environments, however, all MCU coatings do not perform equivalently and should be tested prior to field use.
7. A Relative Humidity (RH) below 30 % may cause unacceptable slow curing, whereas a RH above 83 % may cause too fast of a cure with unacceptable carbon dioxide bubbling.
8. MCU coatings which contain the solvent xylene as either the principle or one of the solvent components may cause film bubbling when DFTs exceed 3.0 mils.
9. The use of MCU topcoats employing 100% aliphatic resins will contain large numbers of urea links which, when compared to two-component aliphatic urethanes, give rise to lower UV resistance.

RECOMMENDATIONS

At present, the Naval Facilities Engineering Service Center (NFESC) does not recommend MCU coating systems for use in the painting of erected antenna towers. If the antenna tower is in a disassembled state and transported to a painting shop where both application and environmental conditions are controlled, then MCU coating systems are acceptable for use on either new or existing antenna towers. NFESC recommends additional performance testing on coating systems, including MCU's, applied under the same extreme environmental conditions encountered in the field, using field application procedures. Up to fifteen high-performance coating systems should be selected and subsequently evaluated under the above conditions.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. Joseph Brandon (Naval Facilities Engineering Command), Mr. Doug Eakin (Oregon State Department of Transportation), and MCU Coating Vendors A - H. Mr. Brandon, through his support and technical insight, assisted in identifying several of the laboratory tests which proved to be critical in directing the outcome of this effort. Mr. Doug Eakin, who took time out from his busy schedule to share Oregon State's experiences using MCU coatings on bridges, for providing the locations of several bridges coated with MCU coatings, and for patiently answering 1001 questions from one author in particular. Last, the authors wish to thank the MCU coating suppliers for participating in the study and, in addition, for providing topcoats, using experimental pigments, in the two FAA colors.

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1. "Federal Aviation Administration Advisory Circular Number 70/7460-1H: Obstruction Marking and Lighting". Federal Aviation Administration, Washington DC, June 1991.
2. "Naval Computer and Telecommunications Command Factsheet: Coating Antenna Towers". Naval Facilities Engineering Service Center (NFESC), Port Hueneme CA, Dec. 1992.
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4. Oregon State Department of Transportation: NFESC Conversations and Visits with Mr. Douglas Eakin. 9/98 – 1/99.
5. American Society for Testing and Materials (ASTM). Philadelphia, PA.
6. S-L. Chong, Y. Yoa, "Laboratory Testing of Performance of Moisture-Cured Urethanes on Steel". The Proceedings of the SSPC 1997 Seminars, SSPC 97-09, Nov 1997.
7. Clive H. Hare, "Protective Coatings: Fundamentals of Chemistry and Composition (SSPC 94 – 17)". Pittsburgh, PA: Technology Publishing Co., 1994.

APPENDIX A

LISTING OF COATING SYSTEMS AND VENDORS BY ASSIGNED LETTER

(LIMITED REPORT VERSION ONLY)

APPENDIX B

FTIR RESULTS GRAPHS AND COMMENTS

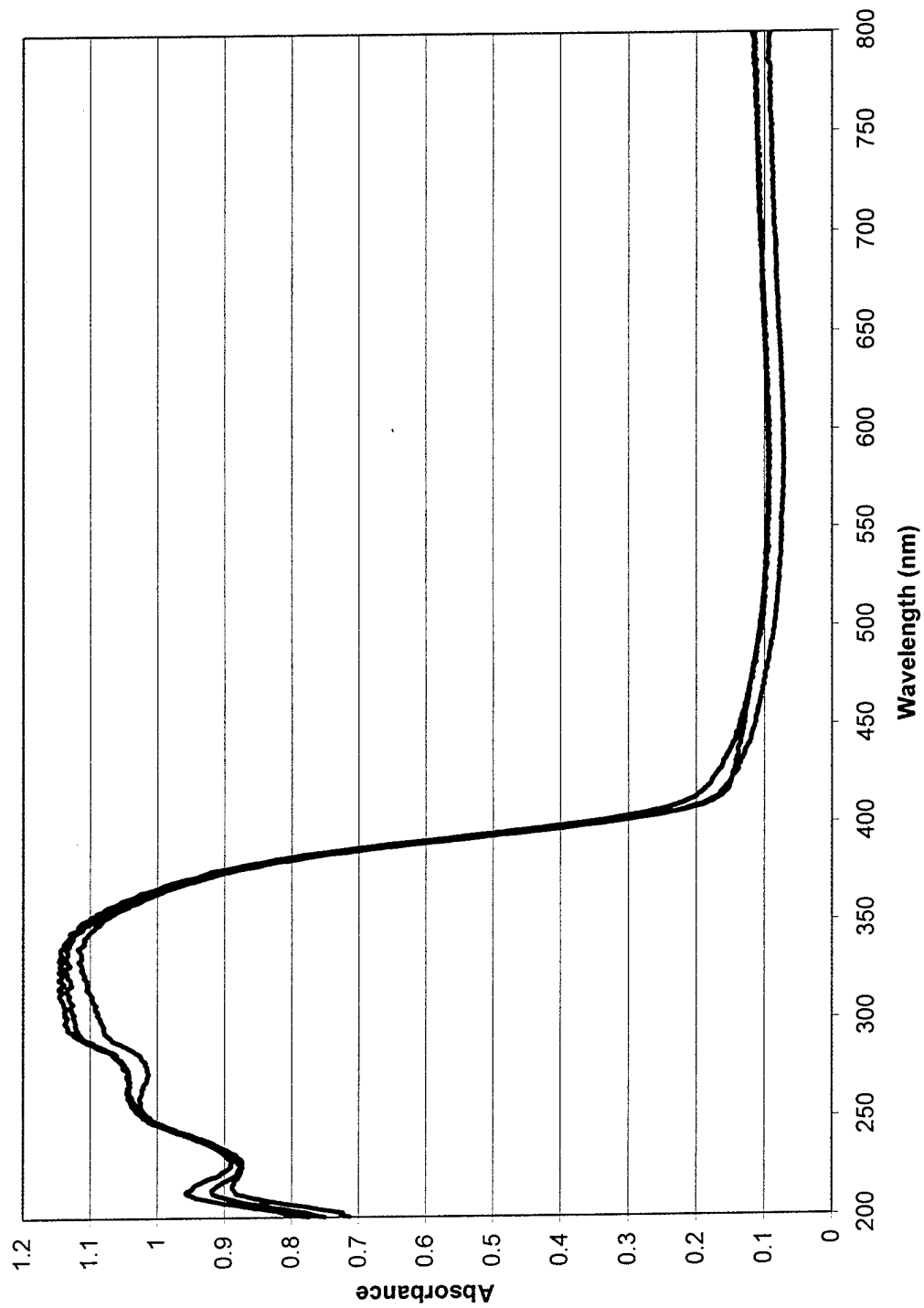
(LIMITED REPORT VERSION ONLY)

APPENDIX C

UV/VIS RESULTS GRAPHS

White Topcoat A

Controls and 3000 Hours UV Exposure



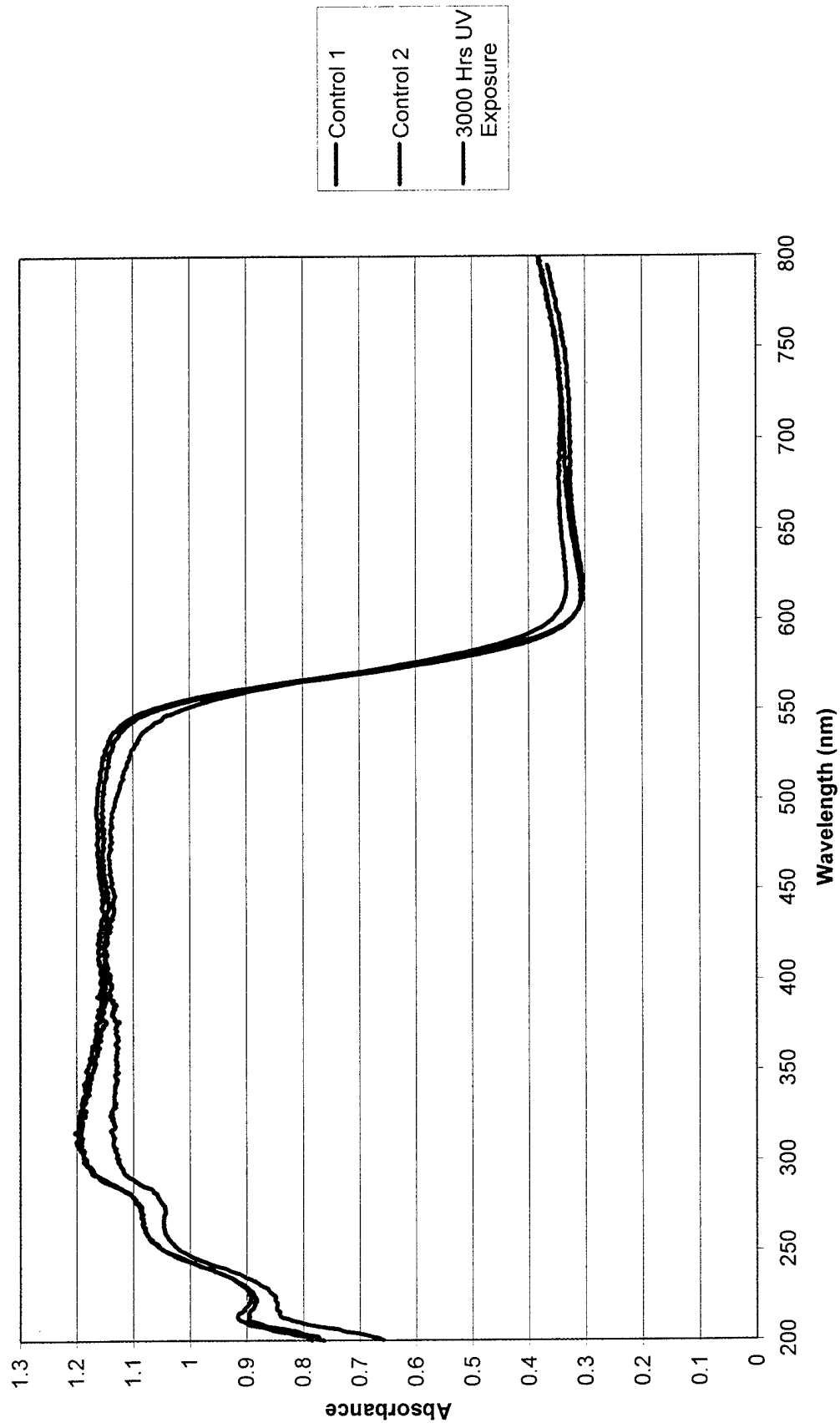
Control 1

Control 2

3000 Hrs UV
Exposure

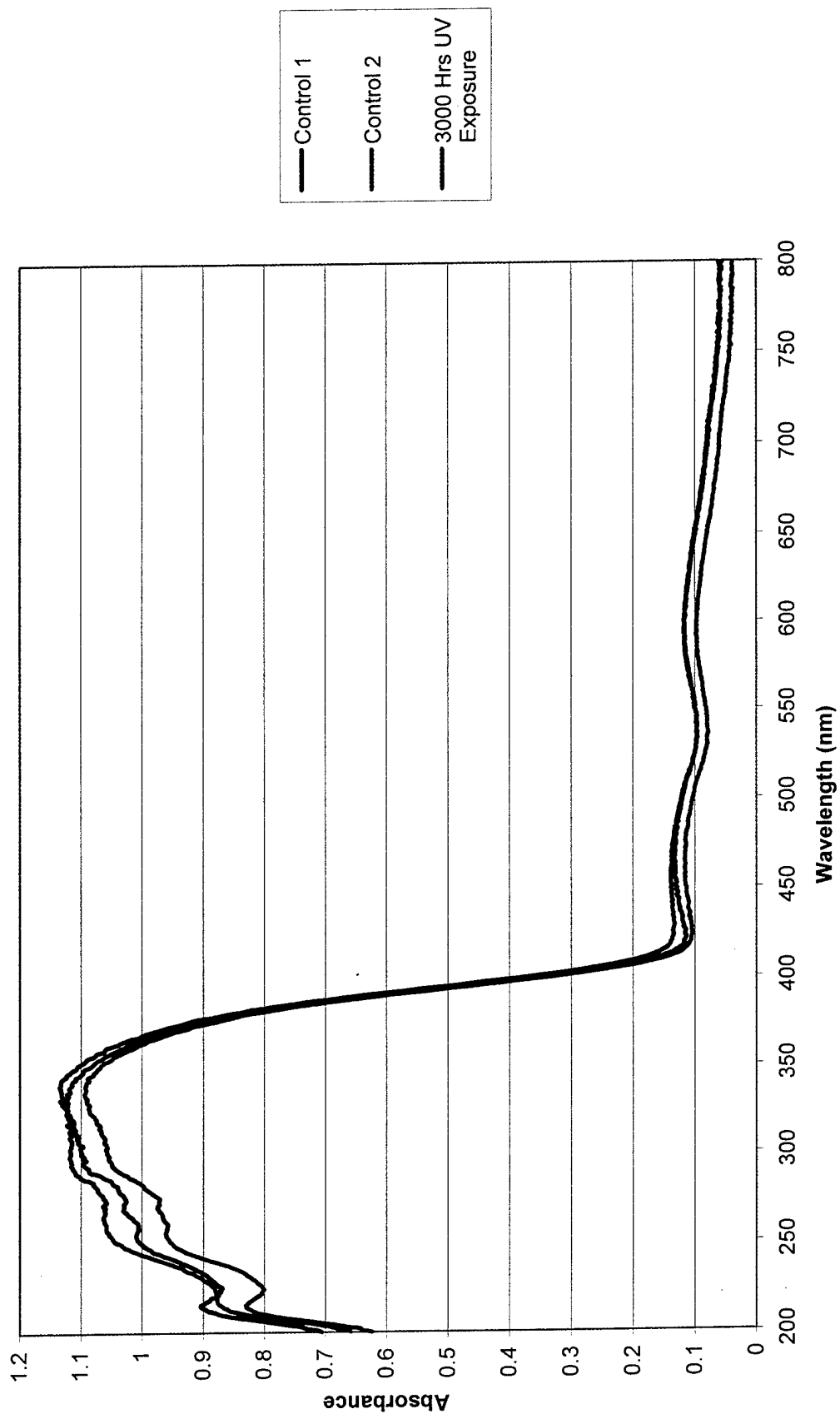
Red-Orange Topcoat A

Controls and 3000 Hours UV Exposure



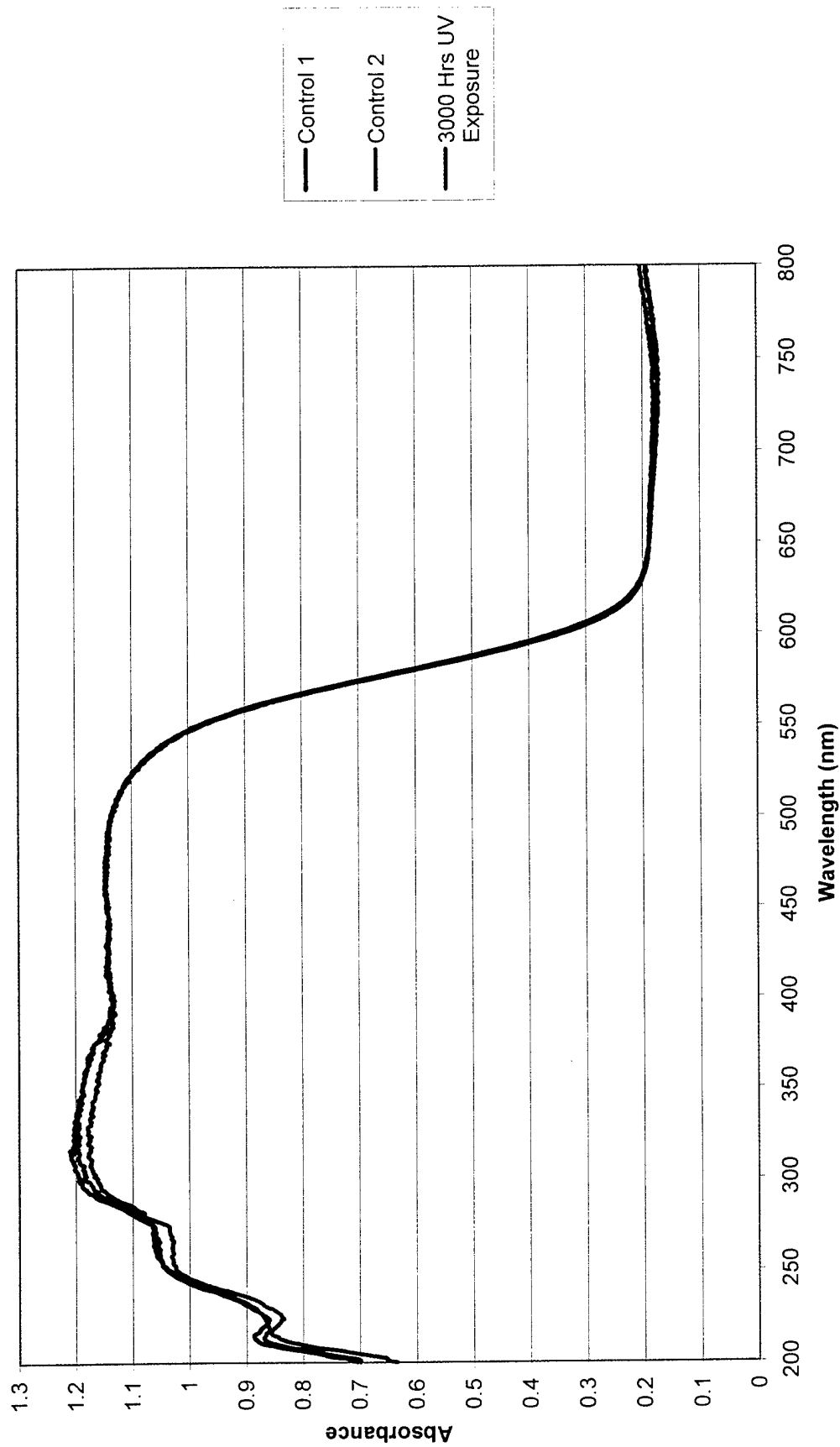
White Topcoat B

Controls and 3000 Hours UV Exposure



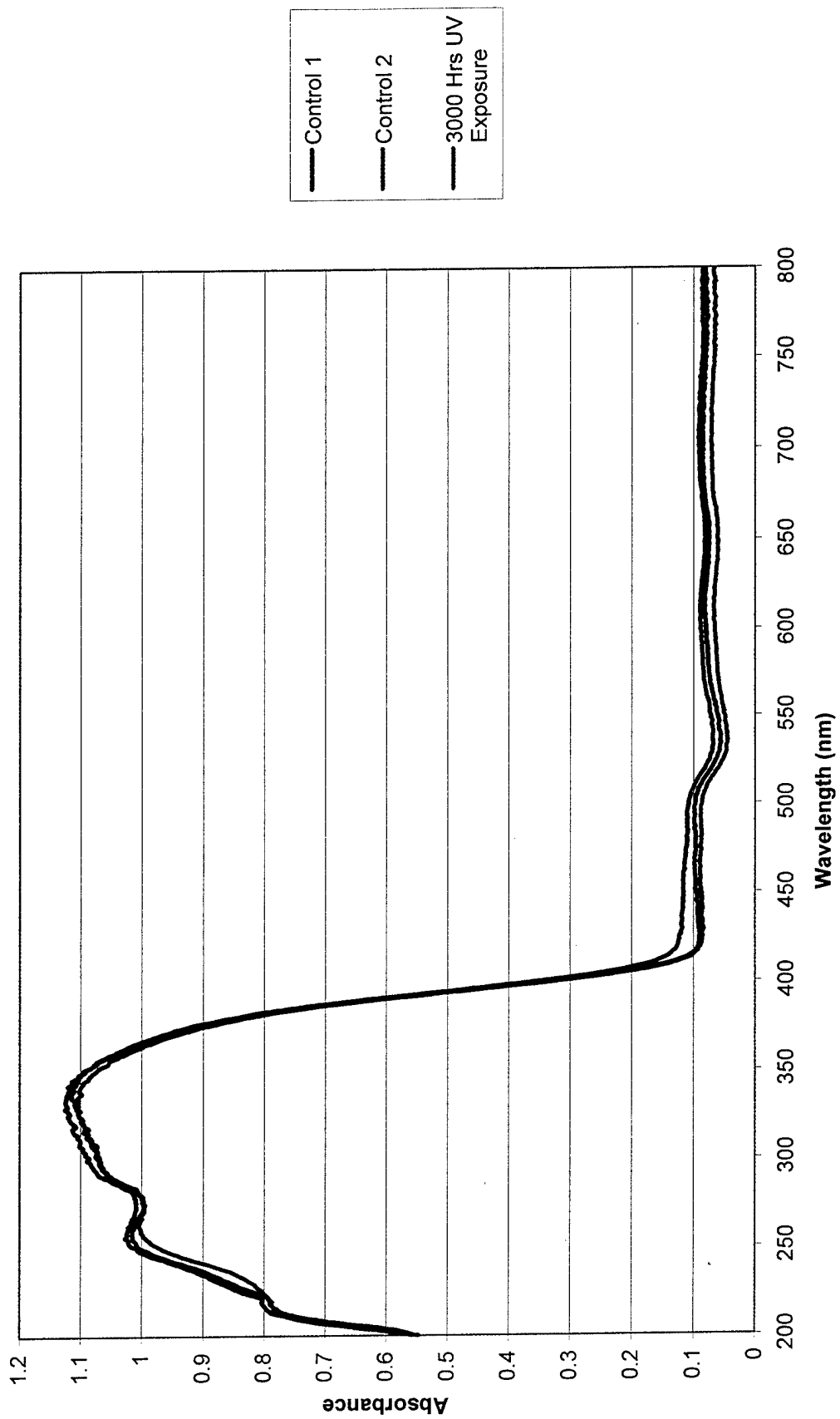
Red-Orange Topcoat B

Controls and 3000 Hours UV Exposure



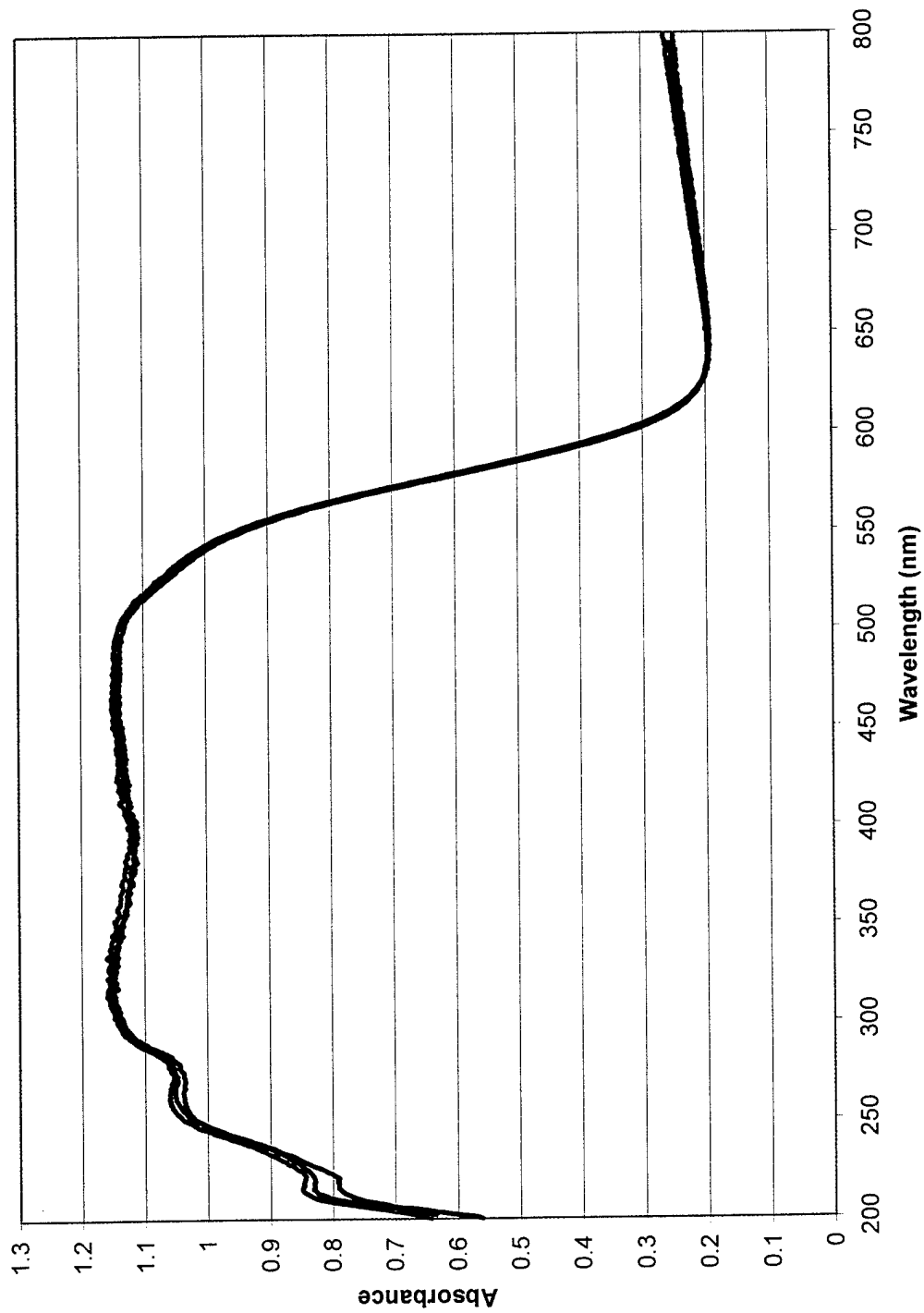
White Topcoat C

Controls and 3000 Hours UV Exposure



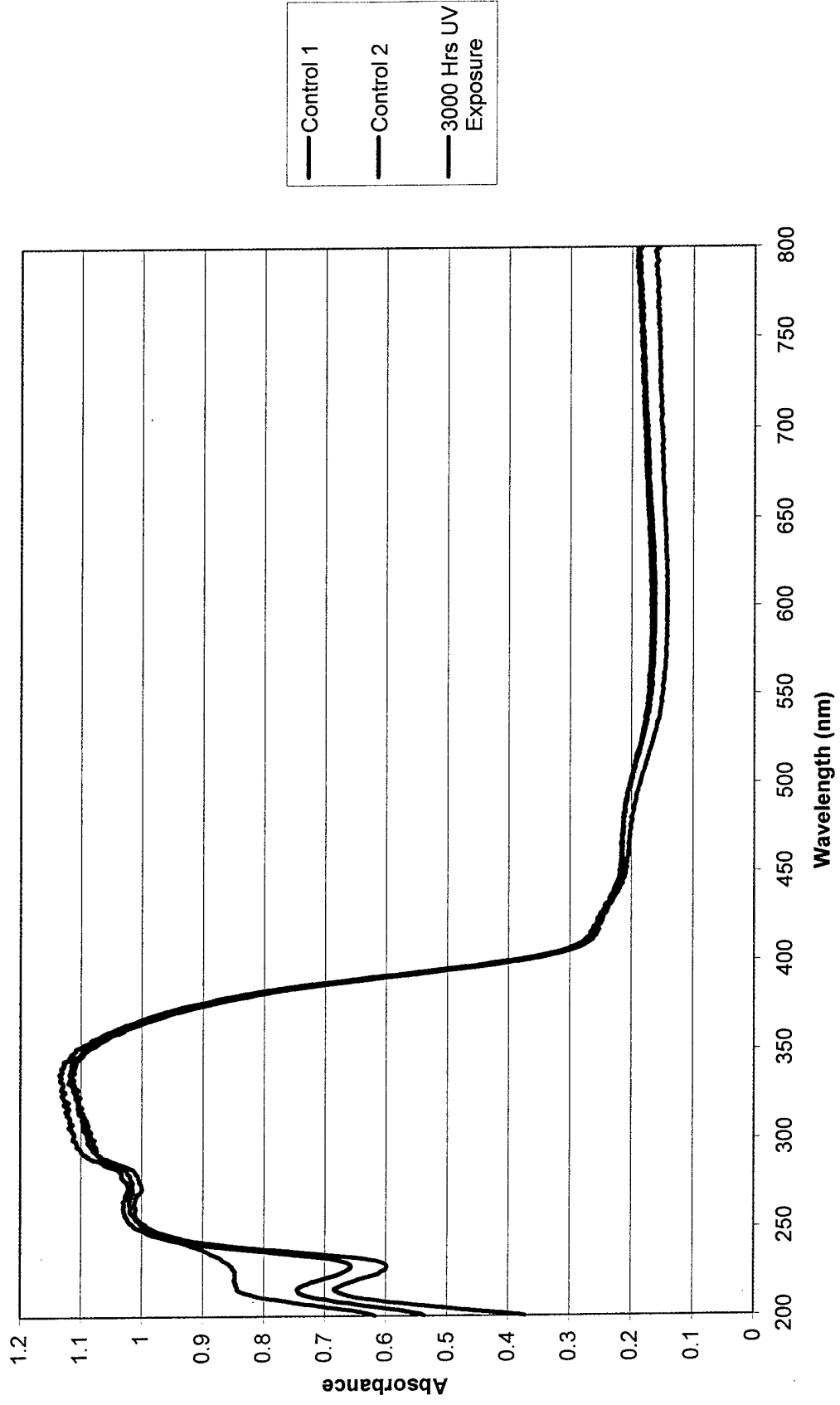
Red-Orange Topcoat C

Controls and 3000 Hours UV Exposure

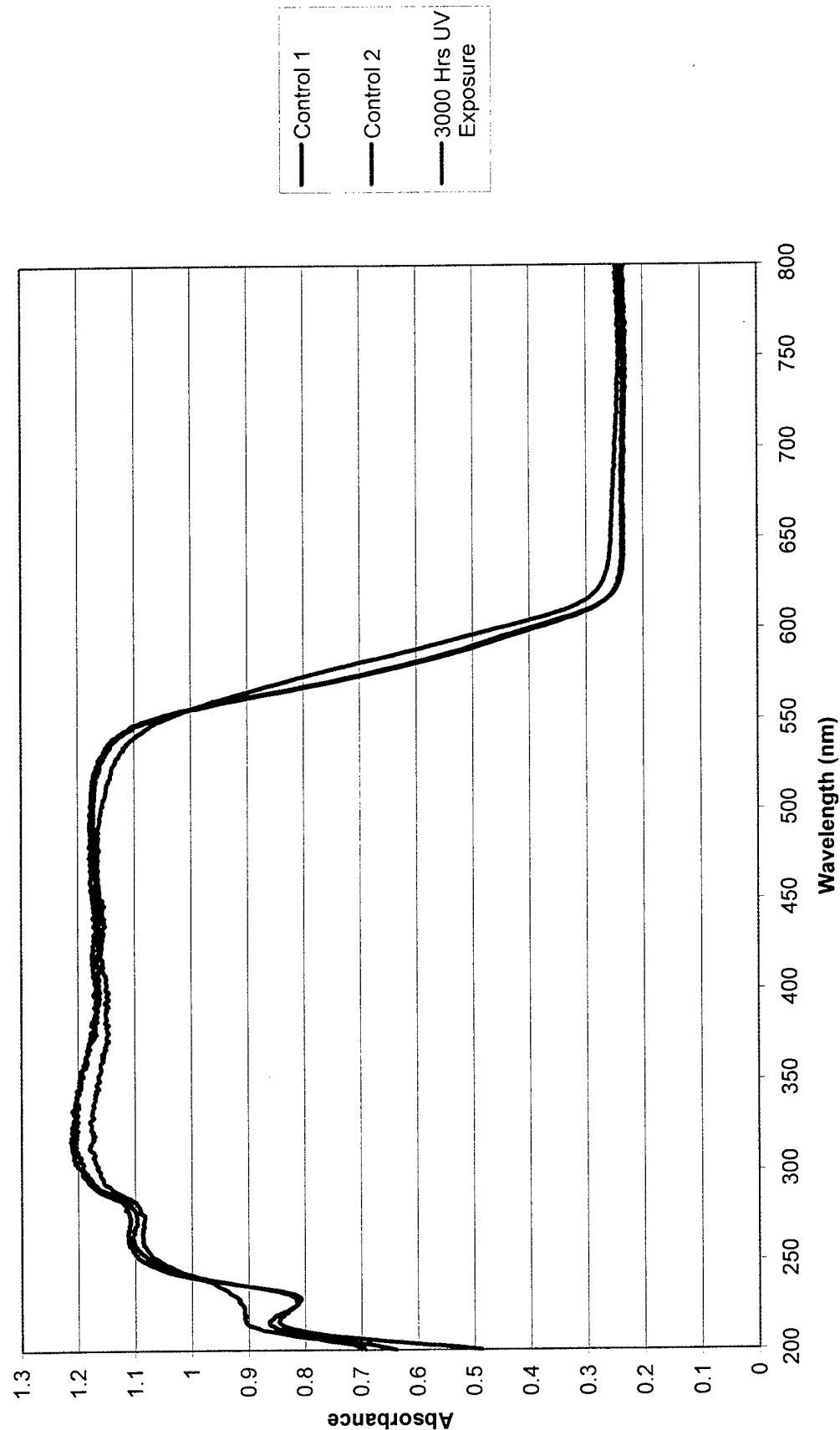


Control 1
Control 2
3000 Hrs UV Exposure

White Topcoat D Controls and 3000 Hours UV Exposure

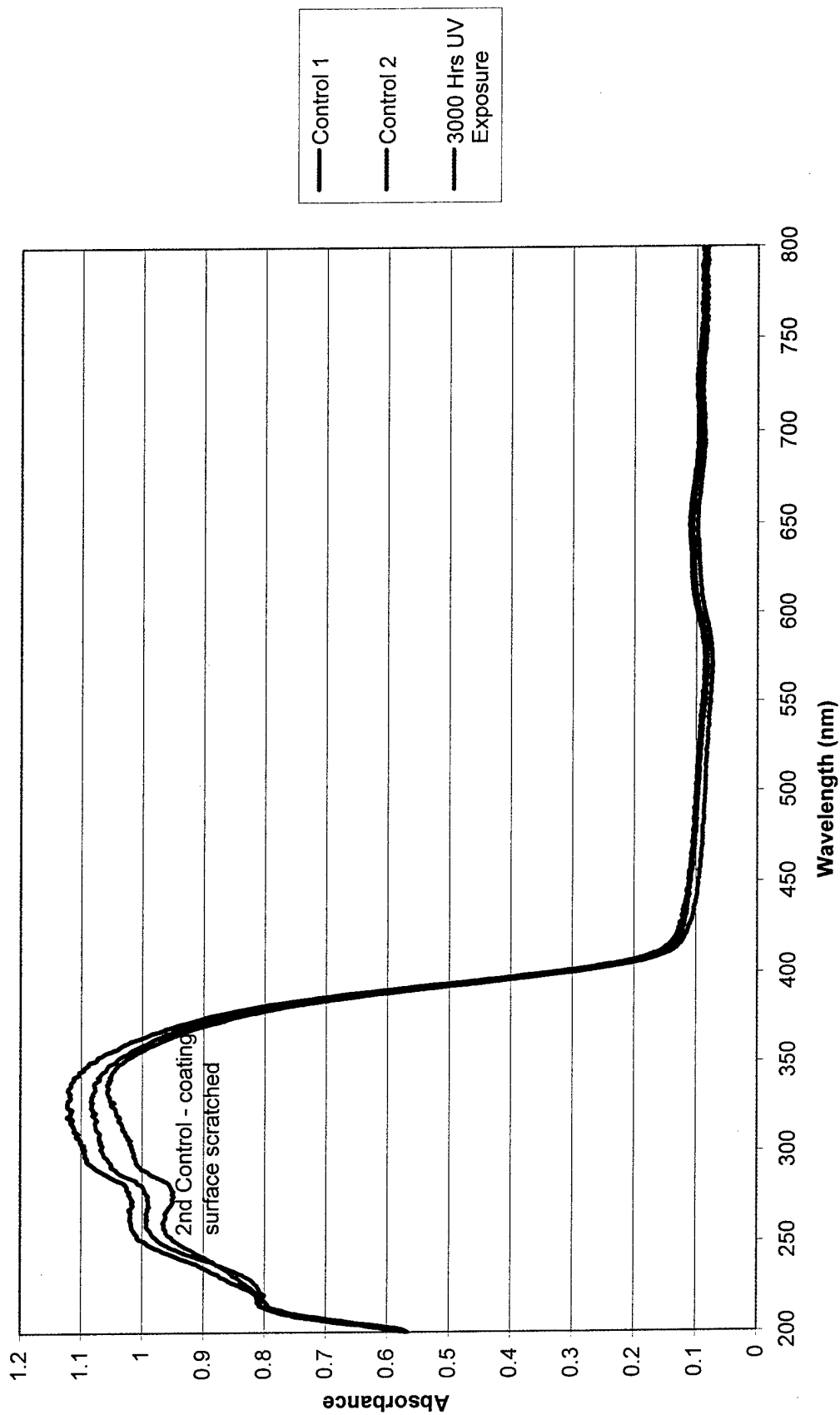


Red-Orange Topcoat D Controls and 3000 Hours UV Exposure



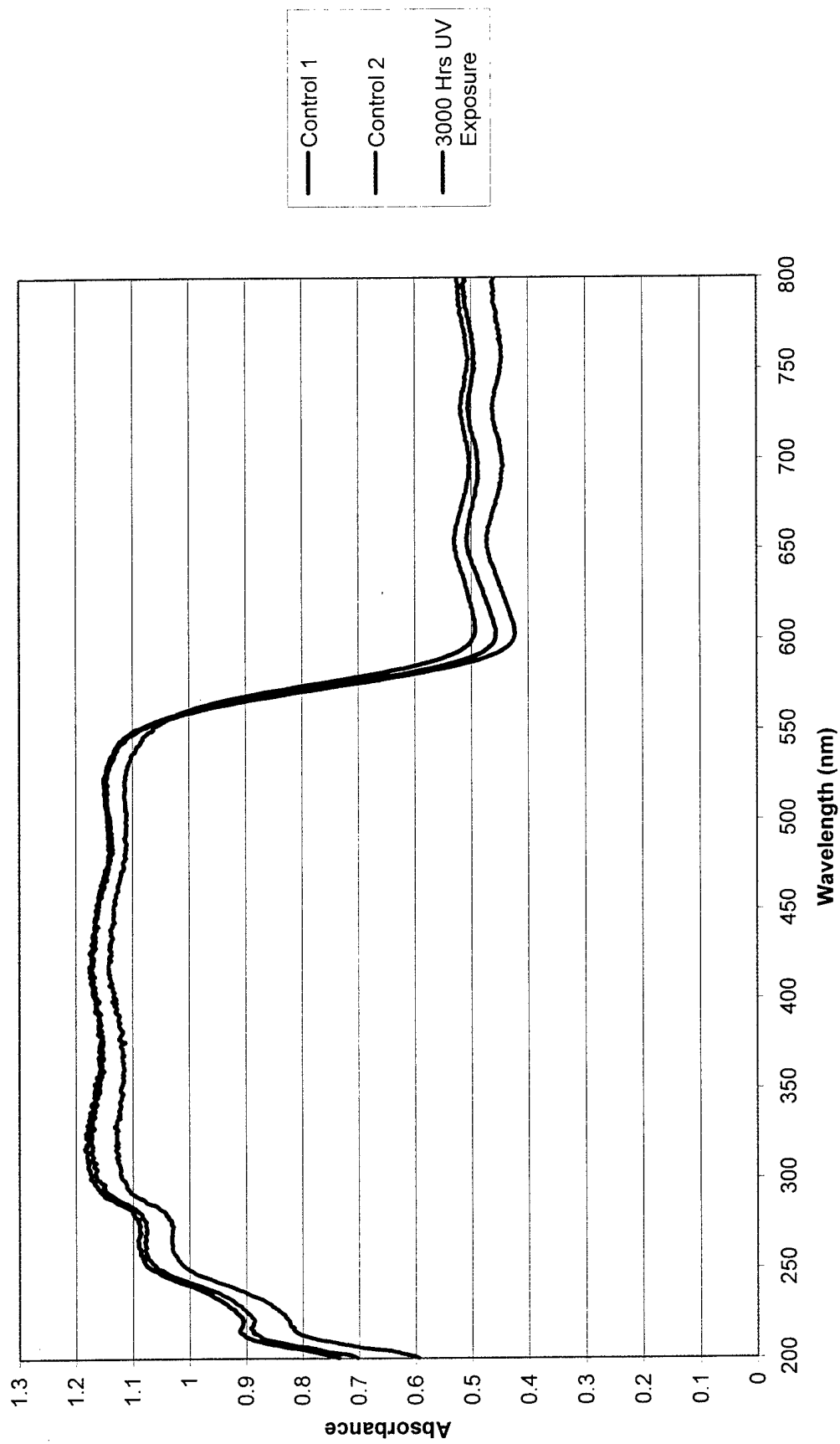
White Topcoat E

Controls and 3000 Hours UV Exposure

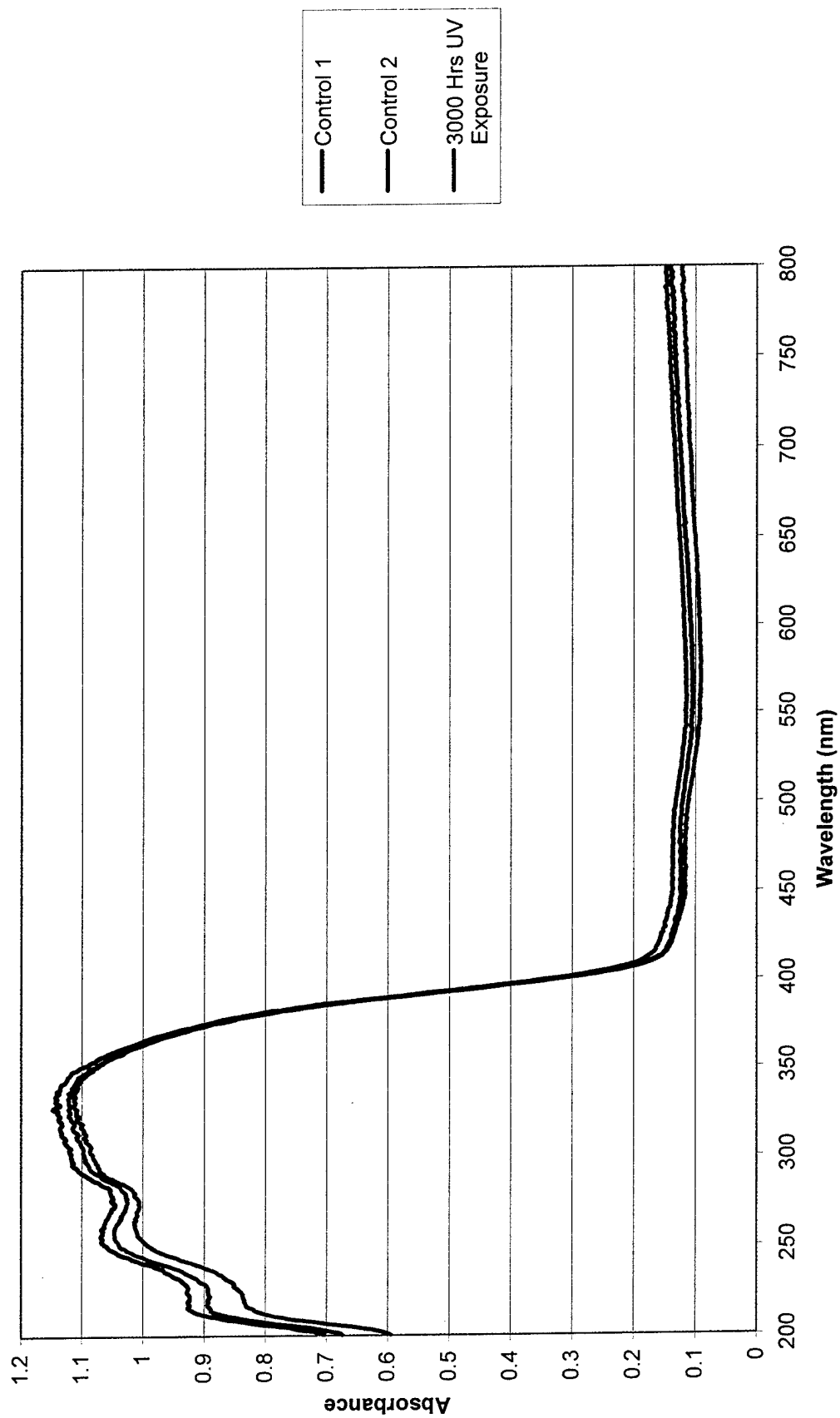


Red-Orange Topcoat E

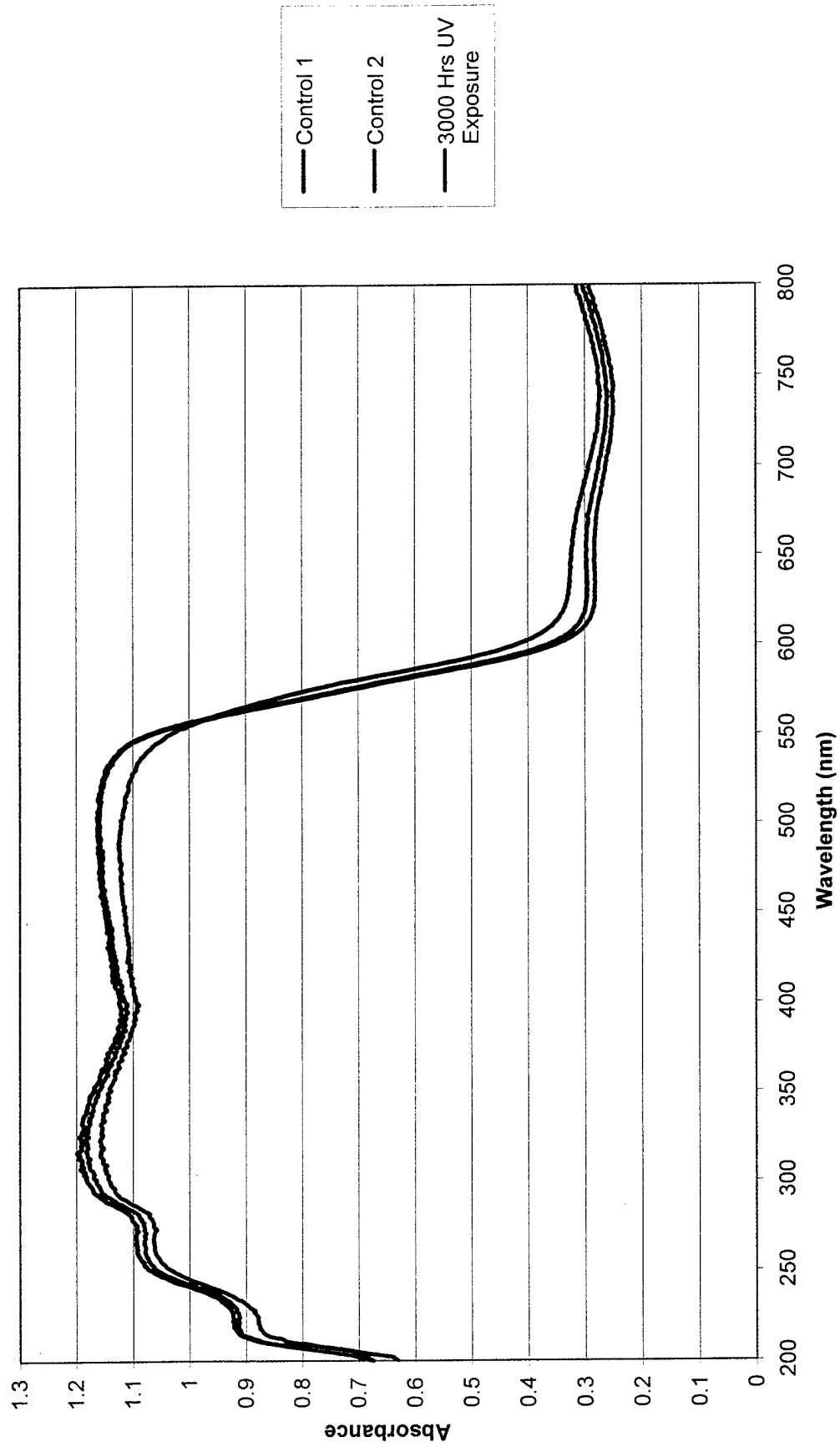
Controls and 3000 Hours UV Exposure



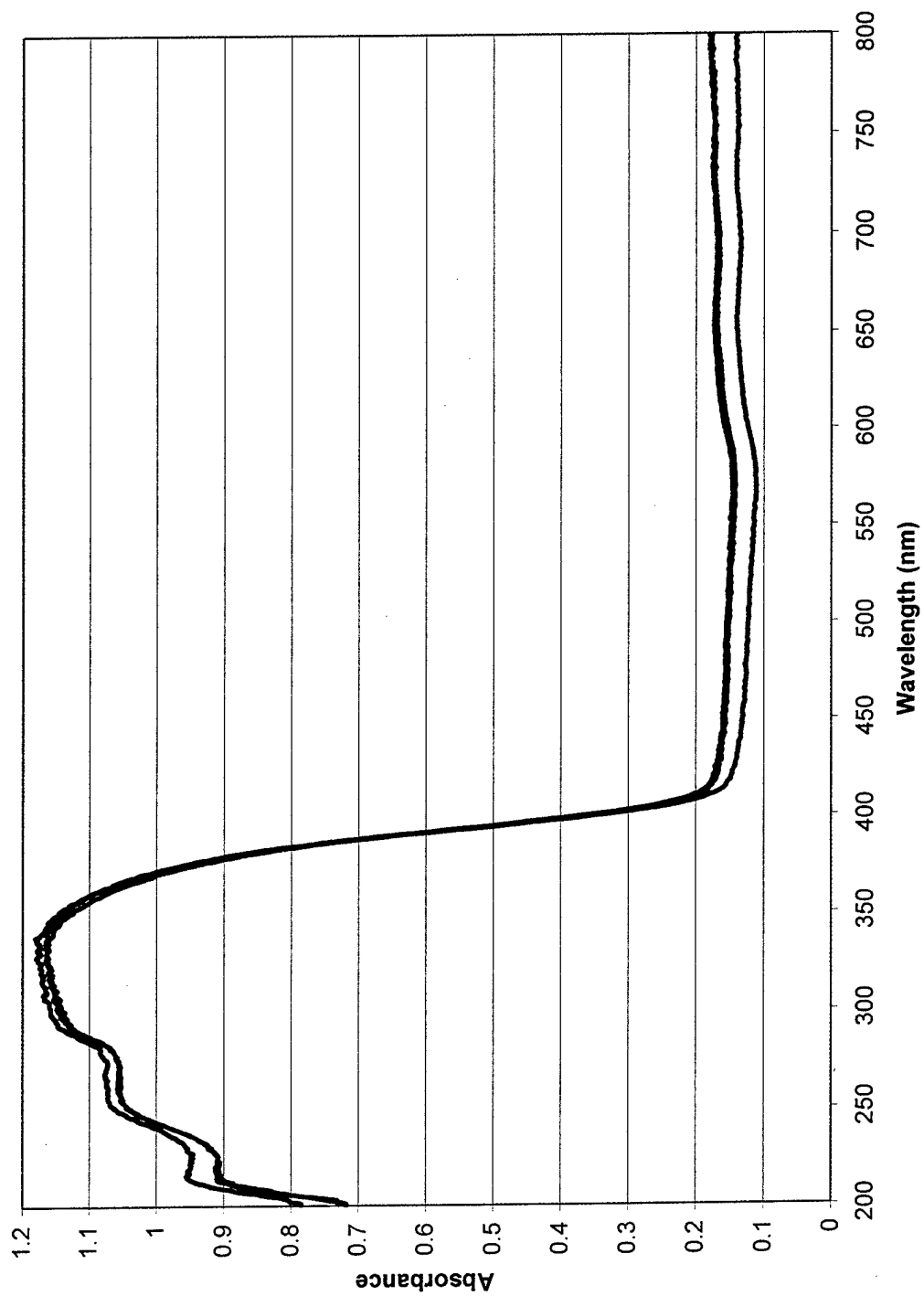
White Topcoat F Controls and 3000 Hours UV Exposure



Red-Orange Topcoat F Controls and 3000 Hours UV Exposure

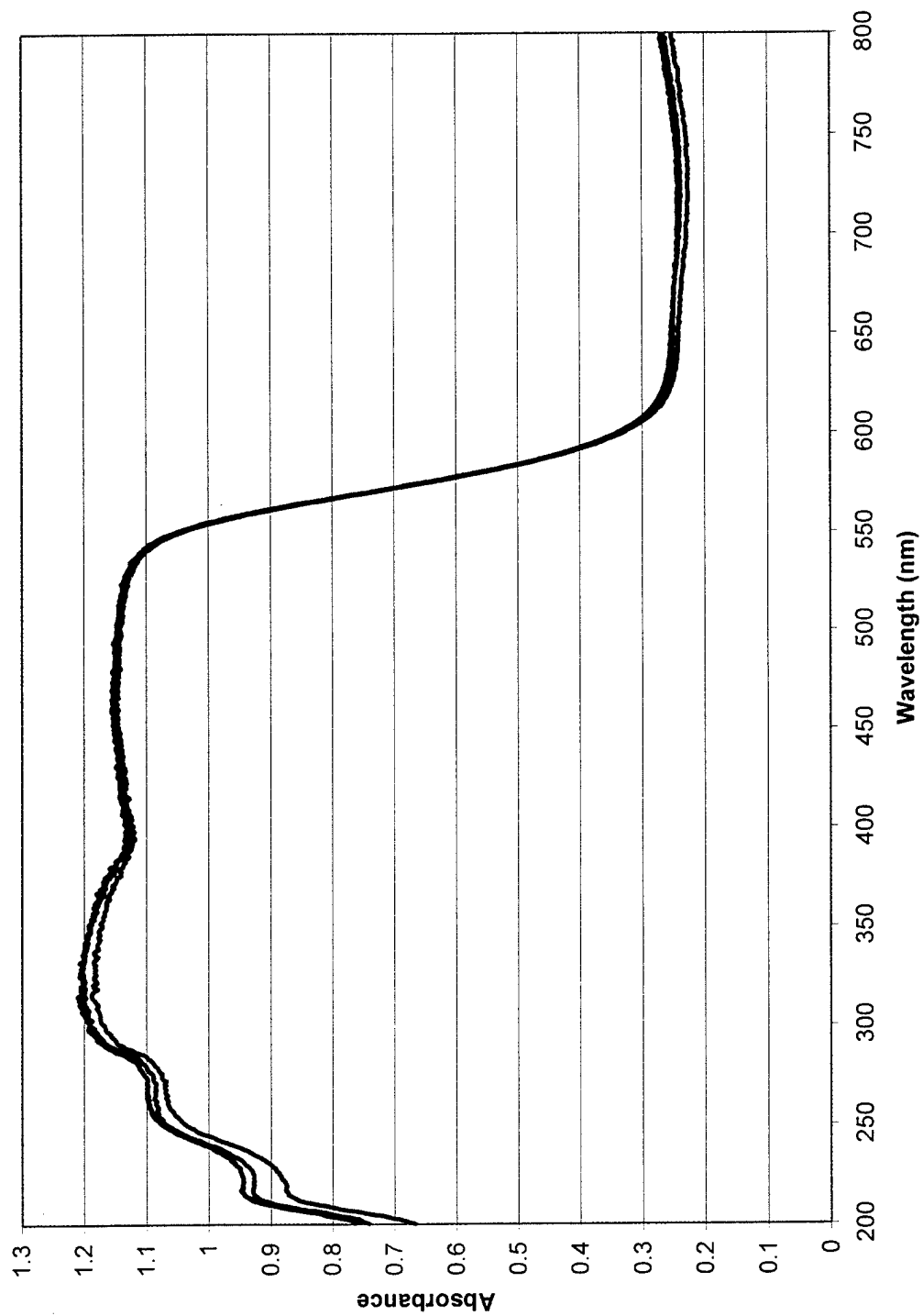


White Topcoat G Controls and 3000 Hours UV Exposure



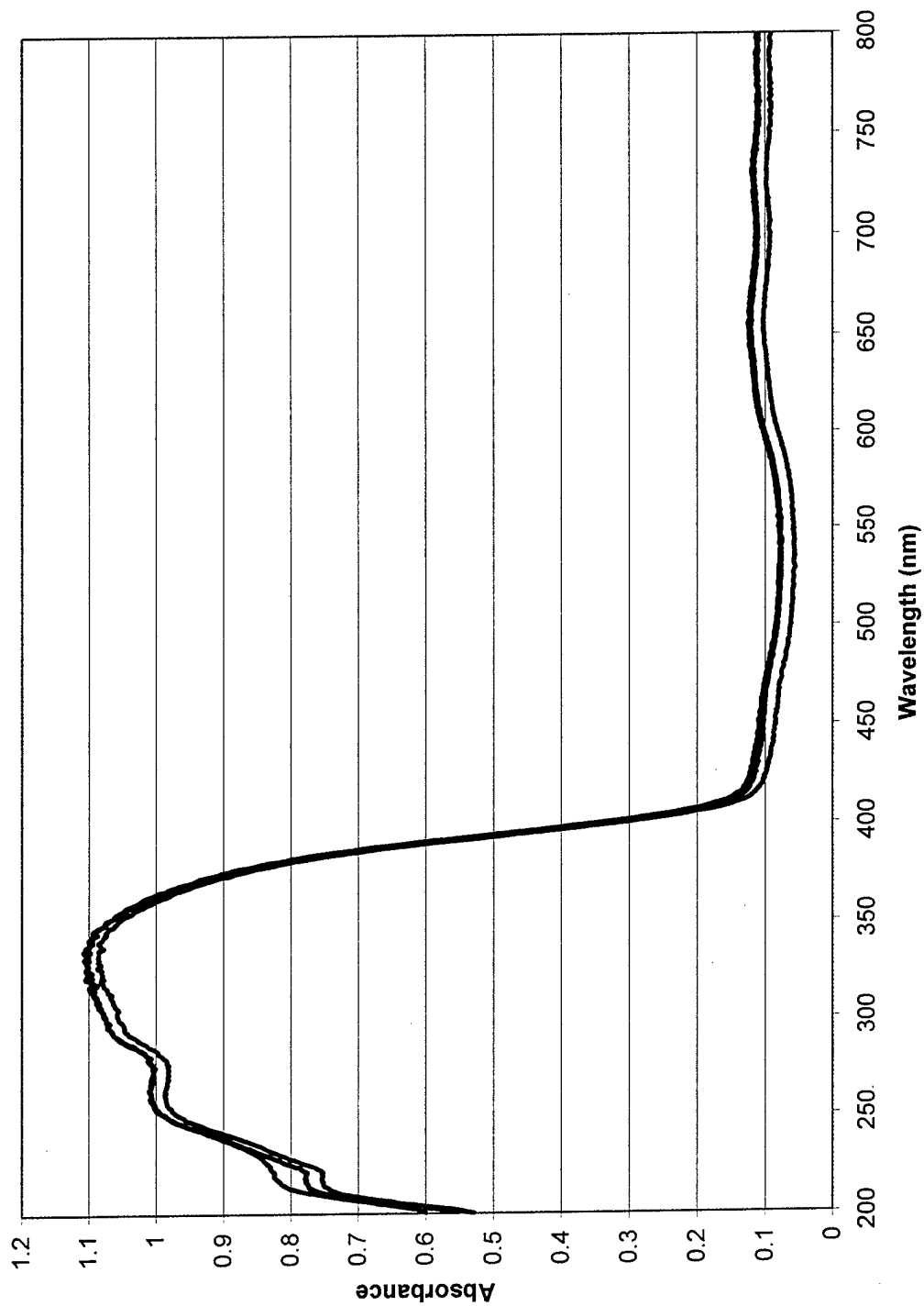
Control 1
Control 2
3000 Hrs UV Exposure

Red-Orange Topcoat G Controls and 3000 Hours UV Exposure



Control 1
Control 2
3000 Hrs UV Exposure

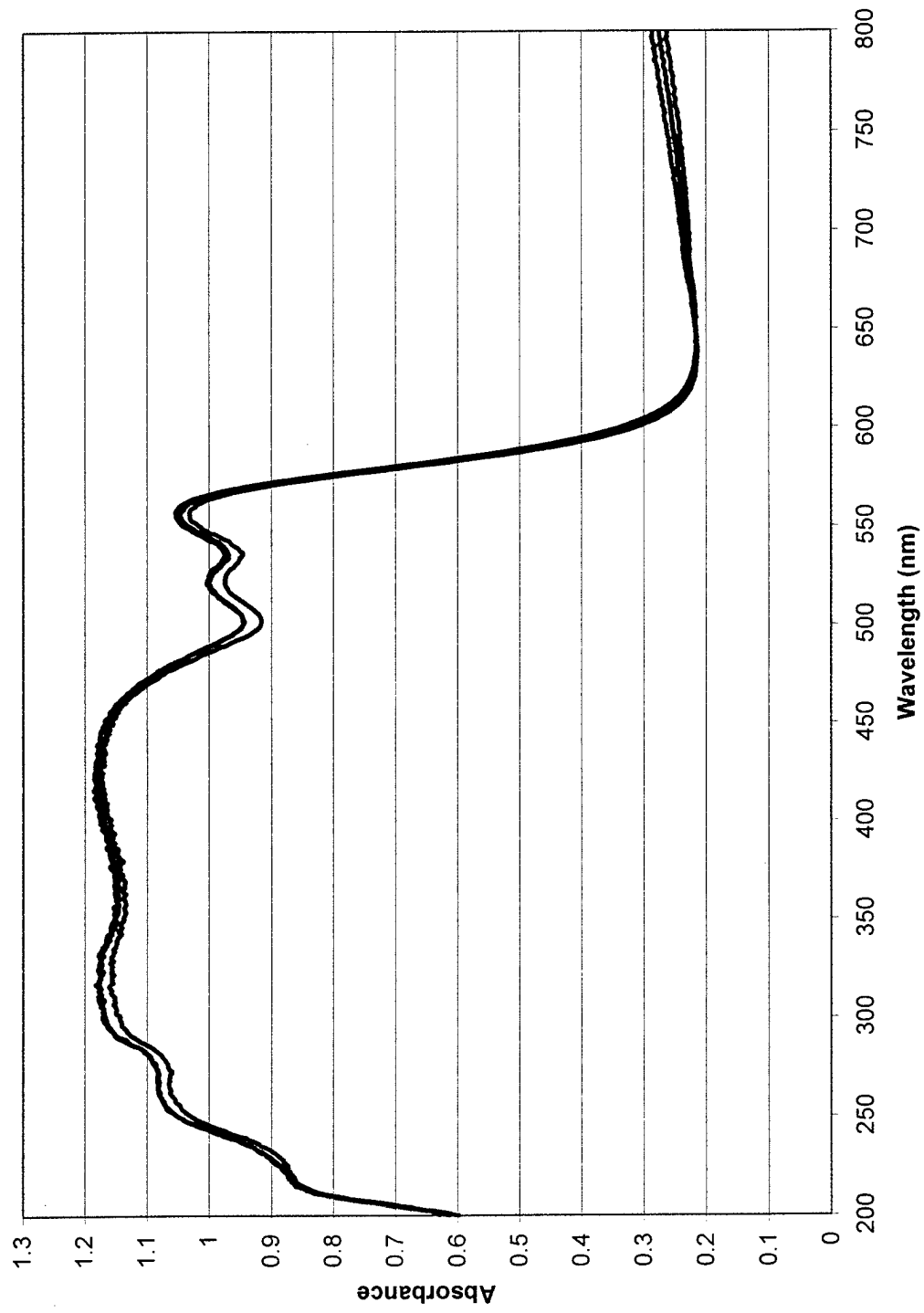
White Topcoat H Controls and 3000 Hours UV Exposure



— Control 1
- - Control 2
... 3000 Hrs UV Exposure

Red-Orange Topcoat H

Controls and 3000 Hours UV Exposure



Control 1
Control 2
3000 Hrs UV Exposure

APPENDIX D

SPECULAR GLOSS RESULTS BEFORE AND AFTER QUV TESTING

SPECULAR GLOSS RESULTS BEFORE AND AFTER QUV TESTING

Coating System A

Before Schedule #1	Before Schedule #2
20.0 (white)	18.3 (white)
11.6 (red-orange)	13.7 (red-orange)
After Schedule #1	After Schedule #2
23.0 (white)	21.4 (white)
17.9 (red-orange)	16.1 (red-orange)
Schedule #1 Gloss Δ^1	Schedule #2 Gloss Δ^1
+ 3.0 (white)	+ 3.1 (white)
+ 6.3 (red-orange)	+ 2.4 (red-orange)

Coating System B

Before Schedule #1	Before Schedule #2
74.9 (white)	69.5 (white)
62.8 (red-orange)	74.4 (red-orange)
After Schedule #1	After Schedule #2
73.8 (white)	71.3 (white)
77.0 (red-orange)	75.6 (red-orange)
Schedule #1 Gloss Δ^1	Schedule #2 Gloss Δ^1
- 1.1 (white)	+ 1.8 (white)
+ 14.0 (red-orange)	+ 1.2 (red-orange)

¹ "+" values indicate a gloss increase whereas "-" values indicated a gloss decrease.

Coating System C

Before Schedule #1	Before Schedule #2
37.3 (white)	35.0 (white)
69.7 (red-orange)	67.9 (red-orange)
After Schedule #1	After Schedule #2
17.7 (white)	15.4 (white)
46.9 (red-orange)	37.2 (red-orange)
Schedule #1 Gloss Δ^1	Schedule #2 Gloss Δ^1
- 19.6 (white)	- 19.6 (white)
- 22.8 (red-orange)	- 30.7 (red-orange)

Coating System D

Before Schedule #1	Before Schedule #2
32.7 (white)	35.6 (white)
39.4 (red-orange)	43.4 (red-orange)
After Schedule #1	After Schedule #2
54.4 (white)	15.6 (white)
40.3 (red-orange)	19.8 (red-orange)
Schedule #1 Gloss Δ^1	Schedule #2 Gloss Δ^1
+ 21.7 (white)	- 20.0 (white)
+ 0.9 (red-orange)	- 23.6 (red-orange)

¹ "+" values indicate a gloss increase whereas "-" values indicated a gloss decrease.

Coating System E

Before Schedule #1	Before Schedule #2
82.5 (white)	77.1 (white)
83.7 (red-orange)	84.5 (red-orange)
After Schedule #1	After Schedule #2
81.0 (white)	80.7 (white)
85.9 (red-orange)	81.3 (red-orange)
Schedule #1 Gloss Δ^1	Schedule #2 Gloss Δ^1
- 1.5 (white)	+ 3.6 (white)
+ 2.2 (red-orange)	- 3.2 (red-orange)

Coating System F

Before Schedule #1	Before Schedule #2
54.5 (white)	53.6 (white)
18.9 (red-orange)	25.1 (red-orange)
After Schedule #1	After Schedule #2
32.0 (white)	33.3 (white)
13.5 (red-orange)	11.8 (red-orange)
Schedule #1 Gloss Δ^1	Schedule #2 Gloss Δ^1
- 22.5 (white)	- 20.3 (white)
- 5.4 (red-orange)	- 13.3 (red-orange)

¹ "+" values indicate a gloss increase whereas "-" values indicated a gloss decrease.

Coating System G

Before Schedule #1	Before Schedule #2
73.5 (white)	68.9 (white)
68.9 (red-orange)	64.5 (red-orange)
After Schedule #1	After Schedule #2
69.9 (white)	69.5 (white)
64.8 (red-orange)	62.6 (red-orange)
Schedule #1 Gloss Δ^1	Schedule #2 Gloss Δ^1
- 3.6 (white)	+ 0.6 (white)
- 4.1 (red-orange)	- 1.9 (red-orange)

Coating System H

Before Schedule #1	Before Schedule #2
81.6 (white)	85.6 (white)
57.4 (red-orange)	48.9 (red-orange)
After Schedule #1	After Schedule #2
81.6 (white)	84.1 (white)
49.5 (red-orange)	44.5 (red-orange)
Schedule #1 Gloss Δ^1	Schedule #2 Gloss Δ^1
0.0 (white)	- 1.5 (white)
- 7.9 (red-orange)	- 4.4 (red-orange)

¹ "+" values indicate a gloss increase whereas "-" values indicated a gloss decrease.